METHOD AND APPARATUS FOR PROVIDING
A DUAL CURRENT-PERPENDICULAR-TO-PLANE (CPP) GMR
SENSOR WITH IMPROVED TOP PINNING

5   BACKGROUND OF THE INVENTION

1.   Field of the Invention.

This invention relates in general to magnetic sensors, and more particularly to a

method and apparatus for providing a dual current-perpendicular-to-plane (CPP) GMR

10   sensor with improved top pinning.

2.   Description of Related Art.

Magnetic recording is a key segment of the information-processing industry.

While the basic principles are one hundred years old for early tape devices, and over forty

15   years old for magnetic hard disk drives, an influx of technical innovations continues to

extend the storage capacity and performance of magnetic recording products. For hard

disk drives, the areal density or density of written data bits on the magnetic medium has

increased by a factor of more than two million since the first disk drive was used for data

storage. Areal density continues to grow due to improvements in magnetic recording

20   heads, media, drive electronics, and mechanics.

Magnetic recording heads have been considered the most significant factor in

areal-density growth. The ability of the magnetic recording heads to both write and

subsequently read magnetically recorded data from the medium at data densities well into

the gigabits per square inch (Gbits/in^2) range gives hard disk drives the power to remain the dominant storage device for many years to come.

Important components of computing platforms are mass storage devices including magnetic disk and magnetic tape drives, where magnetic tape drives are popular, for

5   example, in data backup applications. Write and read heads are employed for writing magnetic data to and reading magnetic data from the recording medium. The read and write heads are connected to processing circuitry that operates according to a computer program to implement the writing and reading functions.

A magnetoresistive (MR) sensor changes resistance in the presence of a magnetic

10   field. Recorded data can be read from a recorded magnetic medium, such as a magnetic disk, because the magnetic field from the recorded magnetic medium causes a change in the direction of magnetization in the read element, which causes a corresponding change in the sensor resistance.

A magnetoresistive (MR) sensor detects magnetic field signals through the

15   resistance changes of a sensing element as a function of the strength and direction of magnetic flux being sensed by the sensing element. Conventional MR sensors, such as those used as MR read heads for reading data in magnetic recording disk and tape drives, operate on the basis of the anisotropic magnetoresistive (AMR) effect of the bulk magnetic material, which is typically permalloy. A component of the read element

20   resistance varies as the square of the cosine of the angle between the magnetization direction in the read element and the direction of sense current through the read element. Recorded data can be read from a magnetic medium, such as the magnetic disk in a

magnetic disk drive, because the external magnetic field from the recorded magnetic medium (the signal field) causes a change in the direction of magnetization in the read element, which in turn causes a change in resistance of the read element. This change in resistance may be used to detect magnetic transitions recorded on the recording media.

5   In the past several years, prospects of increased storage capacity have been made possible by the discovery and development of sensors based on the giant magnetoresistance (GMR) effect, also known as the spin valve effect. In a spin valve sensor, the GMR effect varies as the cosine of the angle between the magnetization of the pinned layer and the magnetization of the free layer. Magnetic sensors utilizing the GMR

10   effect are found in mass storage devices such as, for example, magnetic disk and tape drives and are frequently referred to as spin valve sensors. In operation, a sense current is caused to flow through the read head and therefore through the sensor. The magnetic flux from the disc causes a rotation of the magnetization vector in at least one of the sheets, which in turn causes a change in the overall resistance of the sensor. As the

15   resistance of the sensor changes, the voltage across the sensor changes, thereby producing an output voltage.

Recent hard disk drive designs have utilized the Current In-Plane (CIP) structure, where the sense current travels between the magnetic shields parallel to the sensor plate. Such a design has produced optimism that areal densities of 100 Gbits/in^2 are possible,

20   However, research efforts continue to find even better read heads so that areal densities may be boosted into the many hundreds of Gbits/in^2 range.

One such discovery is the Current-Perpendicular-to-Plane (CPP) structure, whereby the sense current travels from one magnetic shield to the other, perpendicular to the sensor plate. The CPP head provides an advantage over the CIP head because as the sensor size becomes smaller, the output voltage of a CPP head becomes larger, thus

5   providing an output voltage that is inversely proportional to the square root of the sensor area.

For ultra high areal density applications, there are at least two limitations that result from these arrangements. First, the read gap in that arrangement is limited by the spin valve thickness. Second, due to the current perpendicular-to-the-plane model, the

10   magnetoresistance of this spin valve structure is insufficient for ultrahigh areal density applications. In a dual CPP GMR sensor, a pair of magnetic shields serves as electrical contact leads to carry sense current flowing perpendicular-to-the-plane of the magnetoresistance device.

Furthermore, in a dual CPP GMR sensor, the first and second pinned layers of the

15   AP pinned structure are typically made of cobalt (Co). Unfortunately, cobalt has high coercivity, high magnetostriction and low resistance. When the first and second pinned layers of the AP pinned structure are formed they are sputter deposited in the presence of a magnetic field that is oriented perpendicular to the ABS. This sets the easy axis (e.a.) of the pinned layers perpendicular to the ABS.

20   In the self-pinned spin valve, the self-pinned layer may be formed of a single layer of a single material or may be a composite layer structure of multiple materials. It is noteworthy that a self-pinned spin valve requires no additional external layers applied

adjacent thereto to maintain a desired magnetic orientation and, therefore, is considered to be an improvement over the anti-ferromagnetically pinned spin valve.

In the presence of some magnetic fields, the magnetic moment of the pinned layer can be rotated anti-parallel to the pinned direction. The question then is whether the

5   magnetic moment of the pinned layer will return to the pinned direction when the magnetic field is relaxed. This depends upon the strength of the exchange coupling field and the coercivity of the pinned layer. If the coercivity of the pinned layer exceeds the exchange coupling field, the exchange coupling field will not be strong enough to bring the magnetic moment of the pinned layer back to the original pinned direction. Until the

10   magnetic spins of the pinning layer are reset the read head is rendered inoperative. On the other hand, the sense current flowing through the CPP element may disturb the direction of magnetization of the top self-pinned layer. In other words, the self-pinned layer is thin so that its demagnetization field may not be greater than the sense current fields acting thereon.

15   It can be seen that there is a need for a method and apparatus for providing a dual current-perpendicular-to-plane (CPP) GMR sensor with improved top pinning.

SUMMARY OF THE INVENTION

To overcome the limitations described above, and to overcome other limitations that will become apparent upon reading and understanding the present specification, the present invention discloses a method and apparatus for providing a dual current-

5   perpendicular-to-plane (CPP) GMR sensor with improved top pinning.

The present invention solves the above-described problems by providing in the passive regions of the sensor a tri-level biasing layer proximate to the top self-pinned layer. The tri-level biasing layer includes a layer of metal oxide layer such as a NiO layer, a layer of alpha-Fe_2O_3 and another metal oxide layer such as NiO. The pinning of

10   the top self-pinned layer is enhanced by the layer of alpha-Fe_2O_3. The layer of alpha-Fe_2O_3 pins the top portion of the pinned layer by providing higher coercivity (H_C) to the pinned layer. The bottom NiO layer serves as an insulation layer to the hard bias layer. The top NiO layer coupled the NiFe at the top and removes exchange coupling to the hard bias layer. Still further, the trilayer of NiO/alpha-Fe_2O_3/NiO allows for a thinner

15   anti-ferromagnetic layer thereby providing for a thinner overall sensor.

A dual CPP GMR sensor in accordance with the principles of the present invention includes a first magnetic shield formed of an electrically conductive and magnetically shielding material, a second magnetic shield formed of an electrically conductive and magnetically shielding material, the first and the second magnetic shields disposed to define

20   a read gap therebetween, a spin valve structure disposed between the first and second magnetic shields, the spin valve structure including a dual spin valve arrangement, the dual spin valve arrangement having a top and bottom spin self-pinned layer and a free

ferromagnetic layers disposed therebetween and a biasing layer disposed proximate the top self-pinned layer in a passive region for pinning the top self-pinned layer.

In another embodiment of the present invention, a magnetic storage system is provided. The magnetic storage system includes a magnetic storage medium having a plurality of tracks for recording of data and a dual CPP GMR sensor maintained in a closely spaced position relative to the magnetic storage medium during relative motion between the magnetic transducer and the magnetic storage medium, the dual CPP GMR sensor further including a first magnetic shield formed of an electrically conductive and magnetically shielding material, a second magnetic shield formed of an electrically conductive and magnetically shielding material, the first and the second magnetic shields disposed to define a read gap therebetween, a spin valve structure disposed between the first and second magnetic shields, the spin valve structure including a dual spin valve arrangement, the dual spin valve arrangement having a top and bottom spin self-pinned layer and a free ferromagnetic layers disposed therebetween and a biasing layer disposed proximate the top self-pinned layer in a passive region for pinning the top self-pinned layer.

In another embodiment of the present invention, a method providing a dual current-perpendicular-to-plane (CPP) GMR sensor with improved top pinning is provided. The method includes forming a first magnetic shield of an electrically conductive and magnetically shielding material, forming a second magnetic shield of an electrically conductive and magnetically shielding material, the first and the second magnetic shields disposed to define a read gap therebetween, forming a spin valve structure between the first and second magnetic shields, the spin valve structure including a dual spin valve

arrangement, the dual spin valve arrangement having a top and bottom spin self-pinned layer and a free ferromagnetic layers disposed therebetween and forming a biasing layer disposed proximate the top self-pinned layer in a passive region for pinning the top self-pinned layer.

5   These and various other advantages and features of novelty which characterize the invention are pointed out with particularity in the claims annexed hereto and form a part hereof. However, for a better understanding of the invention, its advantages, and the objects obtained by its use, reference should be made to the drawings which form a further part hereof, and to accompanying descriptive matter, in which there are illustrated and described

10   specific examples of an apparatus in accordance with the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring now to the drawings in which like reference numbers represent corresponding parts throughout:

Fig. 1 illustrates a storage system according to an embodiment of the present invention;

Fig. 2 illustrates one storage system according to an embodiment of the present invention;

Fig. 3 illustrates a slider mounted on a suspension according to an embodiment of the present invention;

Fig. 4 illustrates an ABS view of the slider and the magnetic head according to an embodiment of the present invention;

Fig. 5 shows an ABS view of a CPP type of spin valve wherein the current flow is perpendicular to the plane of the free layer;

Fig. 6 shows a conventional dual CPP sensor using AP-Coupled free layer to generate magnetoresistance;

Fig. 7 illustrates a dual CPP GMR head 700 according to an embodiment of the present invention; and

Fig. 8 is a flow chart of the method for providing a dual current-perpendicular-to-plane (CPP) GMR sensor with improved top pinning according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

In the following description of the embodiments, reference is made to the accompanying drawings that form a part hereof, and in which is shown by way of illustration the specific embodiments in which the invention may be practiced. It is to be

5 understood that other embodiments may be utilized because structural changes may be made without departing from the scope of the present invention.

The present invention provides a method and apparatus for providing a dual current-perpendicular-to-plane (CPP) GMR sensor with improved top pinning. In the passive regions of the sensor, a tri-level biasing layer is formed proximate to the top self-

10 pinned layer. The tri-level biasing layer includes a layer of NiO, a layer of alpha-Fe_2O_3 and a layer of NiO. The pinning of the top self-pinned layer is enhanced by the layer of alpha-Fe_2O_3. The layer of alpha-Fe_2O_3 pins the top portion of the pinned layer by providing higher coercivity (H_C) to the pinned layer. The bottom NiO layer serves as an insulation layer to9 the hard bias layer. The top NiO layer coupled the NiFe at the top

15 and removes exchange coupling to the hard bias layer. Still further, the trilayer of NiO/alpha-Fe_2O_3/NiO allows for a thinner anti-ferromagnetic layer thereby providing for a thinner overall sensor.

Fig. 1 illustrates an exemplary storage system 100 according to the present invention. A transducer 110 is under control of an actuator 120, whereby the actuator

20 120 controls the position of the transducer 110. The transducer 110 writes and reads data on magnetic media 130. The read/write signals are passed to a data channel 140. A signal processor 150 controls the actuator 120 and processes the signals of the data

channel 140 for data exchange with external Input/Output (I/O) 170. I/O 170 may

provide, for example, data and control conduits for a desktop computing application,

which utilizes storage system 100. In addition, a media translator 160 is controlled by the

signal processor 150 to cause the magnetic media 130 to move relative to the transducer

5   110. The present invention is not meant to be limited to a particular type of storage

system 100 or to the type of media 130 used in the storage system 100.

Fig. 2 illustrates one particular embodiment of a multiple magnetic disk storage

system 200 according to the present invention. In Fig. 2, a hard disk drive storage system

200 is shown. The system 200 includes a spindle 210 that supports and rotates multiple

10   magnetic disks 220. The spindle 210 is rotated by motor 280 that is controlled by motor

controller 230. A combined read and write magnetic head 270 is mounted on slider 260

that is supported by suspension 250 and actuator arm 240. Processing circuitry

exchanges signals that represent information with read/write magnetic head 270, provides

motor drive signals for rotating the magnetic disks 220, and provides control signals for

15   moving the slider 260 to various tracks. Although a multiple magnetic disk storage

system is illustrated, a single magnetic disk storage system is equally viable in

accordance with the present invention.

The suspension 250 and actuator arm 240 position the slider 260 so that

read/write magnetic head 270 is in a transducing relationship with a surface of magnetic

20   disk 220. When the magnetic disk 220 is rotated by motor 280, the slider 240 is

supported on a thin cushion of air (air bearing) between the surface of disk 220 and the

ABS 290. Read/write magnetic head 270 may then be employed for writing information

to multiple circular tracks on the surface of magnetic disk 220, as well as for reading information therefrom.

Fig. 3 illustrates a sensor assembly 300. In Fig. 3, a slider 320 is mounted on a suspension 322. First and second solder connections 302 and 308 connect leads from the sensor 318 to leads 310 and 314, respectively, on suspension 322 and third and fourth solder connections 304 and 306 connect to the write coil (not shown) to leads 312 and 316, respectively, on suspension 322.

Fig. 4 is an ABS view of slider 400 and magnetic head 410. The slider has a center rail 420 that supports the magnetic head 410, and side rails 430 and 460. The support rails 420, 430 and 460 extend from a cross rail 440. With respect to rotation of a magnetic disk, the cross rail 440 is at a leading edge 450 of slider 400 and the magnetic head 410 is at a trailing edge 470 of slider 400.

The above description of a typical magnetic recording disk drive system, shown in the accompanying Figs. 1-4, is for presentation purposes only. Storage systems may contain a large number of recording media and actuators, and each actuator may support a number of sliders. In addition, instead of an air-bearing slider, the head carrier may be one that maintains the head in contact or near contact with the disk, such as in liquid bearing and other contact and near-contact recording disk drives.

Fig. 5 shows an ABS view 500 of a conventional CPP type of spin valve, wherein the current flow is perpendicular to the plane of the free layer. Spin valve head 500 includes top shield 552, bias layer 556, spacer layer 558, free layer 560, second spacer layer 562, pinned layer 563, pinning layer 570, seed layer 572 and bottom shield 574.

Top shield 552 also acts as a shared pole in merged read/write heads. Bias layer 556 is an antiferromagnetic material, such as IrMn, PtMn, NiMn, etc. Spacer layers 558 and 562 may be formed of Cu, Au, Ag, NiFeCr, Al, Ru, etc. Free layer 560 is a ferromagnetic layer, such as NiFe and CoFe. The magnetization of free layer 560 is

5 shown by an arrow on that layer. Pinned layer 563 is a synthetic antiferromagnet or SAF, and includes, for example, first CoFe layer 564, Ru spacer layer 566 and second CoFe layer 568.

When two ferromagnetic layers, such as CoFe layers 564 and 568 are separated by a spacer of an appropriate thickness, the two ferromagnetic layers couple strongly with

10 magnetic moments anti-parallel as shown by the circled "X" (into the paper) and circled dot (out of the paper) on these layers. In Fig. 5, a synthetic antiferromagnet is used as pinned layer 563 to provide a reduced demagnetization field for providing magnetic stability. Alternatively, pinned layer 563 could be a single soft magnetic layer, such as CoFe. Pinning layer 570 is an antiferromagnetic material, for example, such as IrMn,

15 PtMn, NiMn, etc.

Top shield 552 and bottom shield 574 act as electrodes for conducting a sense current. The sense current flows between top shield 552 and bottom shield 574 and through layers 556-572. This mode of operation, where the sense current 580 flows perpendicular to the plane of spacer layer 562, is referred to as current perpendicular-to-

20 plane or CPP mode. Operation in CPP mode provides an enhanced GMR response.

CPP GMR heads as shown in Fig. 5 provide an enhanced GMR response compared to current-in-plane (CIP) GMR heads (which would have leads at the sides of

at least some of layers 556-572 so that the current would flow between the side leads parallel to the layers 556-572).

Fig. 6 shows a conventional dual CPP sensor 600 using AP-Coupled free layer to generate magnetoresistance. The dual CPP sensor 600 includes a first shield 610. The shield 610 may be formed of an electrically conductive and magnetically shielding material. A seed layer 612, for example of PtMn, is formed over the first shield 610. Seed layer 612 facilitates the growth of rest of the sensor structure. A bottom self-pinned layer 620 is formed over the seed layer 612. The bottom self-pinned layer 620 includes a first layer of CoFe 622, an interlayer of Ru 624 and a second layer of CoFe 626. A first barrier layer 630 is formed over the bottom self-pinned layer 620. The first barrier layer 630 may be, for example, a layer of Al_2O_3. The AP-coupled free layer 640 is formed over the first barrier layer 630. The AP-coupled free layer 640 may include a third layer of CoFe 642, an interlayer of Ru 644 and a fourth layer of CoFe 646. A second barrier layer 650 is formed over the AP-coupled free layer 640. A top self-pinned layer 660 is formed over the second barrier layer 650. The top self-pinned layer 660 may include a fifth layer of CoFe 662, an interlayer of Ru 664 and a six layer of CoFe 666. A Ta layer 670 is formed over the top self-pinned layer 660 and a second shield 680 is formed over the Ta layer 670. During operation, current 690 flows perpendicular to the plane of the layers. The first 610 and second 680 shields also act as the electrodes supplying current as well as detection electrodes.

The self-pinning of the top 660 and bottom 620 self-pinned layers is achieved through the perpendicular stress induced anisotropy caused by compressive stress at the

air bearing surface and positive magnetostriction, for example, of the CoFe. The magnetization of the top 660 and bottom 620 self-pinned layers are properly oriented so that their magnetic orientations are at 180 degree from one another so that the signal adds. The layers between the barrier layers form the AP-coupled Free layer 640.

5   The read gap 692 is the length of the sensor between the first 610 and second 680 shield layers. It should be understood that the thinner the length of the read gap 692 the higher the linear read bit density of the read head 600. This means that more bits can be read per inch along the track of a rotating magnetic disk that enables an increase in the storage capacity of the magnetic disk drive. However, thinning the sensors to reduce the

10   length of the read gap 692 results in other difficulties. As discussed above, in the presence of some magnetic fields the magnetic moment of the pinned layers 620, 660 can be rotated anti-parallel to the pinned direction and thereby rendering the read head inoperative. On the other hand, the sense current 690 flowing through the CPP element may disturb the direction of magnetization of the top self-pinned layer 660. In other

15   words, the self-pinned layer 660 is thin so that its demagnetization field may not be greater than the sense current fields acting thereon.

Fig. 7 illustrates a dual CPP GMR head 700 according to an embodiment of the present invention. In Fig. 7, a first shield is formed 710. A seed layer 712 is formed over the first shield layer 710. The seed layer 712 may include a layer of NiFeCr, a layer of

20   NiFe and a layer of PtMn. A bottom self-pinned layer 720 is formed over the first shield 710. The bottom self-pinned layer 720 may include two ferromagnetic layers, .e.g., CoFe and an interlayer, e.g., Ru. A first spacer layer 730 is formed over the bottom self-pinned

layer 720. The first spacer layer 730 may be, for example, a layer of copper. The AP-coupled free layer 740 is formed over the first spacer layer 730. The free layer 740 may include a first layer of CoFe, a layer of NiFe and a second layer of CoFe. A second spacer layer 750 is formed over the AP-coupled free layer 740. The second spacer layer

5   750 may also be, for example, a layer of copper. A top self-pinned layer 760 is formed over the second spacer layer. The top self-pinned layer 760 may include a first layer of CoFe, a layer of Ru and a second layer of CoFe.

A layer of Al_2O_3 770 is formed in the passive areas adjacent to the bottom self-pinned layer 720 on both sides. A hard bias layer 772 is formed over the layer of Al_2O_3

10   770. Adjacent the top self-pinned layer 760, a trilayer 790 of NiO 792, alpha-Fe_2O_3 794 and NiO 796 is formed. A ferromagnetic layer 798, e.g., NiFe, is formed over the top anti-ferromagnetic (AFM) NiO layers 796 and the top self-pinned layer 760. A Ta layer 776 is formed over the NiFe layer 798 and a second shield 780 is formed over the Ta layer 776.

15   During operation, current flows perpendicular to the plane of the layers. The first 710 and second 780 shields also act as the electrodes supplying current as well as detection electrodes. The layers 792, 794, 796 in the stack 790 provide pinning to the NiFe layer 798 by exchange coupling and raising its Hc. The intra film exchange in the NiFe layer 798 then provides pinning to layer 760. The bottom NiO layer 792 serves as

20   an insulation layer to the hard bias layer 772. The top NiO layer 796 couples the NiFe 798 at the top and removes exchange coupling to the hard bias layer 772. Still further,

the layer of NiO 792, layer of alpha-Fe_2O_3 794 and layer of NiO 796 allow a thinner anti-ferromagnetic layer 790 thereby providing for a thinner overall sensor.

Fig. 8 is a flow chart of the method for providing a dual current-perpendicular-to-plane (CPP) GMR sensor with improved top pinning according to an embodiment of the

5   present invention. In Fig. 8, a dual CPP stack having a top and bottom self-pinned layer and a free layer is formed on a first shield 810. In the passive regions, a hard bias layer is formed proximate to at least the bottom self-pinned layer and the free layer 820. A tri-level bias layer is formed in the passive region proximate to the top self-pinned layer 830. A ferromagnetic layer, e.g., NiFe, is formed over the tri-level bias layer and the top self-

10   pinned layer 840. A layer of Ta is formed over the NiFe layer 850. A second shield is formed over the layer of Ta 860.

The foregoing description of the exemplary embodiment of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications

15   and variations are possible in light of the above teaching. It is intended that the scope of the invention be limited not with this detailed description, but rather by the claims appended hereto.